



# **Evaluating Perceptual and Motor Explanations of Mirror-Writing in Children**

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## Abstract

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Mirror writing refers to script produced in the reverse direction. The spontaneous mirror writing observed in children may give us an insight into how writing actions develop. However, there is no consensus on whether mirror writing has a predominately perceptual or motor basis. This study aims to address that question, a) 123 children (mean age = 72 months) from an Irish primary school and preschool engaged in tasks designed to examine the relationship between mirror writing and the spontaneous mirror generalisation which enables a child to recognise a letter and its mirror image (Dehaene, 2007). Specifically, they wrote individual lowercase letters and made orientation judgements about these letters and their mirror images, b) 123 children plus 20 adults engaged in novel motor tasks devised to test whether mirror writing was associated with a difficulty in learning actions requiring a specific direction (Della Sala & Cubelli, 2007). A perceptual basis for mirror writing was supported. There was a correlation between letters mirror written and those perceptually confused during the orientation judgement task ( $r = .62$ ,  $p < .01$ ). Mirror generalisations were found to be more frequent than mirror writing for every letter. This suggests that mirror generalisations may be either the causal or limiting factor for mirror writing. A motor explanation was not supported. These findings and their educational implications are discussed.

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## **Declaration**

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I have read and understood The University of Edinburgh guidelines on Plagiarism and declare that this written dissertation is all my own work except where I indicate otherwise by proper use of quotes and references

## Acknowledgments

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First and foremost, I would like to express my sincere gratitude to my supervisor Rob McIntosh for his expert guidance, patience and advice throughout this project. Thank you for the initial idea and your generous time. I would also like to thank the schools, parents and children that agreed to participate in this study, and to the adult participants who gave up their time to play with children's toy for me. Finally, a very big thank you to my parents, Barry, Jason and Robert for tolerating me throughout the whole process.

# 1. Introduction

Mirror writing refers to script which runs in the opposite to the normal direction. As its name indicates, mirror writing becomes legible when its image is read in a mirror (Blom, 1928). In its complete form all the letters of a word are written in reverse (Figure 1). However, more commonly, individual letters or digits are reversed in a word which is otherwise correctly oriented. The neuropsychological roots of this phenomenon, particularly in children, are yet unclear. What can this childhood mirror writing tell us about the development of writing? To better understand mirror writing, one can examine its nature before evaluating the proposed explanatory hypotheses.



Figure 1: An example of mirror writing of whole name (Katie).

## 1.1. The Nature of Mirror Writing

Mirror writing occurs in normal healthy adults, brain damaged patients and children. Certain individuals, including perhaps most famously Leonardo Da Vinci, have taught themselves to write in reversed script (Della Sala & Cubelli, 2007). Mirror writing has been used in visual art and described in novels and films, such as Stanley Kubrik's *The Shining*. Healthy, normal adults can mirror write when instructed to do so (Schott, 2007), and may also mirror write unintentionally when given unusual writing commands, such as writing on the underside of a table or on their foreheads (Critchley, 1928). Involuntary mirror writing may occur in normal adults when writing with their non-dominant hand (Wang, 1992) and in left-handed individuals under extreme stress (Downey, 1914). It has also been observed in cases when there has been damage to the preferred hand, such as amputation (Schott, 1980).

Mirror writing has been well documented following neurological damage. Acquired mirror writing has been observed following stroke (Wang, 1992) head injury (Streifler & Hofman, 1976) or degenerative disease (Tashiro, Matsumoto, Hamada, & Moriwaka, 1987). This

pathological mirror writing is often transient and confined to particular letters, words or sentences. It may be accompanied by other spatial or directional confusion (Schott, 2007).

The most common incidence of mirror writing is the involuntary reversal of characters or words by children learning to write between the ages of three and seven (Schott, 2007). It was once believed that mirror writing was related to slow intellectual development (Fuller, 1916, Gordon, 1920), or was a 'classical symptom of left-handedness' (Schiller, 1932). However, more recent work has dispelled these beliefs, with no handedness (Della Sala & Cubelli, 2007) or intellectual differences found between mirror writers and normal writers (Fischer, 2011a; Fischer & Tazouti, 2011). Rather, the consensus is that mirror writing in children is a normal stage of learning to write (Cornell, 1985, Della Sala & Cubelli, 2007; Fischer, 2011a).

## **1.2. Mirror Writing Hypotheses**

Mirror writing is clearly a heterogeneous phenomenon; the question is whether this is a single unitary entity or whether mirror writing has a number of causes (Schott, 2007). For more than a century, a number of potential explanations for mirror writing have gone in and out of fashion. These hypotheses will be discussed below.

### ***1.2.1. Perceptual hypotheses***

Orton (1928) proposed 'mirror engrams', like the 'negative of a photograph' (Ireland, 1882), are stored in the non-dominant hemisphere for every word and letter known. Applied to the mirror writing phenomenon in children, the engrams for the letters of the alphabet in both hemispheres would compete until dominance was established. In the case of damage to one hemisphere, the dormant engrams would be released (Della Sala & Cubelli, 2007). While there is some evidence to suggest that visual images are transferred across hemispheres (Bradshaw, Nettleton & Patterson, 1973), the literature does not support this hypothesis. Mirror writing is not consistently associated with the fluent reading of reversed letters and words, known as mirror reading (Corballis & Beale, 1976).

Related to this, the spatial disorientation hypothesis (Heilman, Howell, Valenstein & Rothi, 1980) suggests that mirror writing is a manifestation of left-right confusion. However, the predictions are not supported as there is a dissociation between orientation and directional

abilities (Della Sala & Cubelli, 2007). Also, this hypothesis would suggest that either hand would be equally associated with mirror writing, however, this has not been found to be the case with most brain-damaged patients mirror writing with their non-dominant hand (Della Sala & Cubelli, 2007).

### ***1.2.2. Motor hypotheses***

The motor hypotheses suggest the dominant language hemisphere stores mirror motor programmes for the formation of each character with the contralateral (dominant writing) hand (Critchley, 1928). Motor programs stored in the left-hemisphere (for right hand use) must be transformed for left-handed use, and vice versa (Chan & Ross, 1988). If these motor programs are not transformed correctly for use with the non-dominant hand, mirror writing would result. The underlying insight into the motor hypotheses is the influence of adduction and abduction when writing (McIntosh & Della Sala, in press). Abductive (outwards from the body midline) movements are believed to be smoother, more accurate, more rapid and less fatiguing than adductive, or inwards, movements (Dreman, 1977; Reed and Smith, 1961). For example, the learned writing direction of a right-handed Westerner is abductive. When writing with the left-hand, this Westerner would more readily write leftwards (abductively), producing reversed script - unless the correct mental transformation is made.

According to this hypothesis, as children learning to write have not yet learned a consistent direction, errors may be made as they improvise the direction of writing with either hand. Normal adults may unintentionally mirror write by failing to transform motor actions while distracted or otherwise impaired. This hypothesis can account for letters mirrored in words which are otherwise correctly oriented. However, it does little to explain why the starting point and direction of word or letter strings can be impaired, or why mirror writing occurs without the use of learned motor programmes, for example mirror writing with alphabet tiles (Della Sala & Cubelli, 2007).

### ***1.2.3. Directional apraxia hypothesis***

Della Sala & Cubelli (2007) propose a unitary account for brain injured patients and young children, built upon the motor hypotheses. The motor programmes for writing letters are assumed to contain information about the shapes of the letters, but not the direction (Cubelli

& Della Sala, 2009). Thus, mirror writing reflects a lack of the appropriate directional knowledge for learned actions, whether it is not yet stable in the case of children, or temporarily inaccessible due to damage.

This hypothesis also assumes that abductive movements are preferred over adductive movements. This can account for the observation that a right handed patient (who has presumably lost directional knowledge), will mirror write more often with their (non-dominant) left hand than their dominant hand, as the writing direction would be dictated by hand used i.e. abductive movements with the right hand would result in correct writing, whereas abductive movements with the left would result in mirror writing. It can also account for mirror writing polyglots, such as the right-handed patient who correctly wrote the rightwards languages, Polish and German, but mirror wrote Hebrew, which runs leftwards (Streifler & Hofman, 1976). The opposite performance would be expected with the left-hand (Della Sala & Cubelli, 2007).

An explanation was also offered on why children mirror write with either hand, rather than choosing abductive movements. According to this hypothesis, the cognitive system is bi-directional at birth. This allows for learning to turn on a tap without having to learn how to turn it off separately. Learning a writing direction would essentially mean *unlearning* the unwanted alternative, rather than acquiring one specific writing direction (Della Sala & Cubelli, 2007). It is proposed that mirror writing can be seen as a form of apraxia, relating specifically to the direction of over-learned motor actions (Della Sala & Cubelli, 2007). This hypothesis predicts that mirror writers should encounter the same problems with other motor tasks requiring specific learned directionality, such as dealing cards or turning on and off water taps.

#### ***1.2.4. Neuronal recycling hypothesis***

The ‘neuronal recycling’ hypothesis (Dehaene, 2007; Dehaene & Cohen, 2007) can be seen as a perceptual alternative to the directional apraxia hypothesis. These hypotheses share the assumption that there is a period in development in which children know how to form letters, but do not know their correct orientation (Fischer, 2011a). As with the directional apraxia hypothesis, which suggests our motor systems are bi-directional, the neuronal recycling hypothesis states that our visual systems are similarly bi-directional. For evolutionary purposes

we generalise the original and lateral mirror versions of images which allows for view-invariant object recognition (Dehaene, 2007), for example “a tiger is equally as threatening when seen in right or left profile” (Rollenhagen & Olsen, p. 1509). Corballis and Beale (1971) imagined being transported to a mirrored world, where one would have difficulty reading signs, turning taps and opening bottles. However, most objects in nature, such as the trees, animals, landscapes would appear unchanged. Mirror generalisations are only counterproductive with cultural inventions. These cultural inventions, such as reading and writing, are far too recent to have influenced the human genome (Dehaene et al., 2010). Therefore, the neuronal networks responsible for these processes must be acquired through ‘recycling’ networks of relatively high plasticity which were evolved for other purposes sufficiently similar to reading and writing (Dehaene, 2009; Dehaene et al., 2010; Dehaene & Cohen, 2011).

Unlike most actions, reading (and writing), requires a specific direction. Consequently, when learning to read, the visual mirror generalisation of the letter must be inhibited or unlearned (Dunabeitia et al., 2011). Over the course of learning to read, one must give a special interpretation to letters, inhibiting their mirror generalisation (Dehaene et al., 2010). After reading acquisition, this visual word form area discriminates between the left and right orientation of single letters but continues to exhibit mirror invariance for other images (Pegado, Nakamura, Cohen & Dehaene, 2011). Evidence for the causal role of reading acquisition in the unlearning of mirror generalisations has been found. Illiterate individuals and expert readers of Tamil (which does not have mirror-image letters, such as *b* and *d*), appeared to be unable to discriminate between abstract line drawings and their mirror images, whereas literate readers of other languages had developed the skill of mirror discrimination (Danziger & Pederson, 1998; Pederson, 2003).

It has been found that the sensorimotor actions involved in hand writing may aid the unlearning process. It has been found that hand writing, as opposed to typing, aids visual recognition of letters in children in and adults (Longcamp, et al., 2008; Longcamp, Zerbato-Poudou, & Velay, 2005). This motor knowledge reactivates during the visual processing of letters (Longcamp et al., 2008). The motor program for a letter is not the same as the motor program for its mirror image. For this reason, hand writing’s motor memory may help in disambiguating a letter from its mirror image (Longcamp et al., 2008), which is important for literacy.



With two strong hypotheses explaining mirror writing, namely the neural recycling and the directional apraxia hypotheses, it remains unclear whether mirror writing has a predominately perceptual or motor explanation. As children are the focus of this study, it is important to discuss further research relevant to mirror writing in this age group.

### **1.3. Childhood Mirror Writing**

Mirror writing is often a concern of parents and teachers, falsely believing it to be a sign of dyslexia or dyscalculia. We now know this phenomenon to be a normal occurrence when learning to write. Nonetheless, it is striking that young children write letters (and digits) in mirror form, which they have never been trained to do, as readily and as perfectly formed as the correct form that they have been taught repeatedly (McIntosh & Della Sala, in press). As this unusual, spontaneous ability is lost by adulthood, children may be able to tell us something of the processes responsible for mirror writing and how the ability to write develops.

Although there is strong evidence for a motor account of mirror writing, some perceptual factors also seem to play a role. Do children literally not ‘see’ their errors or are they unaware of the importance of orientation (Hendrickson & Muehl, 1962)? Parents and teachers frequently observe that children do not seem to notice their mirror writing, and even when children are aware of the orientation of their writing they do not necessarily consider these to be errors. This may be because young mirror-writers often do not perceive the difference between letters and their mirror form, for example, Davidson (1935) found that less than 10% of kindergarteners could discriminate between *b* and *d*. Davidson (1935 p.464) gives anecdotal evidence of this; when children were asked to comment on whether *b*’s and *d*’s were the same, some children replied “Yes, this faces this way and that faces that way.” As the neuronal recycling hypothesis suggests, children may generalise the direction of the letter, seeing the letters as correct regardless of orientation, just as a chair facing in either direction is still identified as a chair.

During the period of development in which a child is learning to write, their directional knowledge, and left-right orientation, is still far from complete (Fischer, 2011b). The global writing direction may ‘invade’ the directionality of nonlinguistic domains (Vaid, 1995), which can influence the direction of drawing (Taguchi & Noma, 2005) and spatial ordering of

temporal concepts (Tversky, Kugelmass, & Winter, 1991). It may be that without strong directional tendencies, such as writing in a left-to-right manner, a young child may begin to write anywhere on a page. Situational factors have been found to be conducive to mirror writing. For example, Cornell (1985) demonstrated that when a vertical line bisects a page and a dot is placed on the left of that line to indicate a starting point, children are more likely to mirror write than if their starting position was placed on the right of the line. Young children refuse to write across the bisecting line when beginning on the left of this bisecting line. It seems that children interpret this spatial constraint as “an invitation to write from right-to-left” (Fischer & Tazouti, 2011, p. 9).

Situational factors have a much stronger influence on mirror writing than the individual factors, such as handedness or gender. Fischer (2011a), proposed a theoretical explanation for the tendency for young children to mirror write some letters more often than others, which he called the ‘right writing rule.’ Children may develop this rule for writing as many of the asymmetrical uppercase letters have “their distinctive feature on the right (*B, D, E, F, K, L N, P,* and *R*), face right (*C* and *G*), or have a tail on the right (*Q*)” (Fischer, 2011a, p.760). The reading direction in Western languages also runs rightwards, supporting this rightwards implicit knowledge. Fischer proposes that the right-facing letters should benefit from the activation of this rule, whereas the activation of this rule would induce mirror writing for the left-facing letter *J*. According to this rule the choice of direction for the letters *S* and *Z* should be by chance, as they do not clearly comply with this rule (Fischer, 2011a). Indeed, this hypothesis was supported with the most frequently mirror written letters being *J* (45%) and *Z* (49%) (Fischer, 2011b).

It is not only children who revert to implicit writing rules when unsure of orientation. A study in which right-handed English speaking undergraduate students at the Massachusetts Institute of Technology were asked to write mirror inversions of letters, revealed that there were a greater number of failures to reverse letters with leftwards orientations (*a, d, g, j, q* and *y*) than rightwards facing ones (Reinvang, 1972). Consistent with Fischer’s ‘right writing rule’, he explained; “when instructed to perform mirror inversion, he conceives his task as changing the orientation from rightwards to leftwards” (Reinvang, 1972, p. 290). This study also found a correlation ( $r_s = .47$ ) between the speed of mirror reading and speed of mirror writing, which may reflect some overlap in the neural representation for these processes or the overlapping situations in which these skills were developed.

Further support in favour of overlap between mirror writing and mirror reading has been found recently (Brennan, in press). Young children were asked to decide whether the uppercase asymmetrical letter (which could be a correct form or a mirror image) presented to them was in its correct orientation or reversed. They were also asked to write those letters. There was a strong correlation between the proportion of errors on the perceptual orientation decision task and the proportion of mirror writings for each letter. This was taken as strong support for a perceptual explanation for mirror writing, as the letters most frequently mirror read were those frequently mirror written.

Fischer (2011a) found that children were influenced not only by the implicit right-writing rule but also by visuospatial priming. Fischer experimentally tested the effect of preceding writing by asking preschool children to write particular sequences of uppercase letters and digits. He found that the direction of the preceding letter can induce correct writing of a letter, or mirror writing. For example, when preceded by a correct *C*, the digit 3 was mirror written by 73% of children but when the preceding *C* was mirror written 90% of children correctly wrote the digit 3. This phenomenon cannot be explained by purely sensorimotor priming, as the 3 hidden in *B* does not prime the correct writing of the digit 3, but rather it primed the production of its mirror image 66% of the time (Fischer, 2011b).

Fischer and Tazouti (2011) found that academic level correlated positively with mirror writing. This is consistent with Johansson's (2005) findings that children's mirror writings of numbers correlated with their arithmetic performance. Della Sala and Cubelli (2007; Cubelli & Della Sala, 2009) also support the opinion that the critical variable in whether a child mirror writes is not chronological age *per se*, but rather the stage of writing acquisition. These findings together suggest that mirror writing may occur in almost all children learning to write, depending on situational factors, during the time in which they produce no or incorrect writing and the production of correct writings (Fischer, 2011b; Fischer and Tazouti, 2011).

#### **1.4. Aims and Hypotheses**

This study aimed to answer whether mirror writing has a motor basis, a perceptual basis or both. The first part of the study consists of language tasks designed to examine a possible association between mirror generalisations (Dehaene, 2007) and mirror writing, and the

second part comprises of novel motor tasks which aim to test and extend the directional apraxia hypothesis (Della Sala & Cubelli, 2007).

## **2. Part 1: Association between Mirror Writing and Mirror Generalisation**

The first part of the study aimed to examine whether there is a perceptual element to mirror writing. The children were asked to read and write individual asymmetrical letters to gauge their language experience level and to gather a sample of mirror writing. As Fischer & Tazouti (2011) found that mirror writing is more likely when the letters are recalled from memory, as opposed to copying, the children were only asked to write the letters they already knew, along with writing their own name on a blank page, so as not to impose any situational constraints.

They also engaged in a perceptual orientation decision task based on the lowercase letters they could accurately name. This was closely based on the task used by Brennan (in press), who used uppercase letters. They were asked to decide whether the letter presented to them was oriented correctly or reversed. Orientation errors in this task are referred to as ‘perceptual confusions’, and taken as a measure of the children’s propensity to mirror read. This task was used to examine whether younger children, in particular mirror writers, retained the mirror generalisation proposed by the neuronal recycling hypotheses (Dehaene, 2007). If mirror writing has a perceptual basis then it would be expected that mirror writers have not yet unlearned the unwanted mirror generalisations of letters. In particular, they would retain the mirror generalisations of the letters they mirror write. Recalling Fischer’s (2011a) right-writing rule, the letters most frequently mirror written are left-facing or non-directional. Thus, it would be expected that the mirror generalisations of these letters are retained most frequently. This may suggest that mirror writing occurs when children choose incorrectly from the two possible orientations they perceive to be correct.

There are two main hypotheses related to the perceptual basis of mirror writing:

- The proportion of mirror writings per letter will correlate positively with proportion of perceptual confusions per letter. It is predicted that this will be reflected on a by-child basis; children with higher mirror writing percentages will also make a higher proportion of perceptual confusions.

- The directionality of the letters will predict both mirror writing and perceptual confusions, with the left-facing and non-directional letters will be most frequently mirror written and mirror read.

Developmental trends for mirror writing and perceptual errors were explored. No differences were expected between mirror writers and normal writers for age or gender, although mirror writers were expected to be younger and to have received fewer years schooling. As recent studies have suggested that mirror writing is better described by academic level than chronological age, this study divides participants by school year, rather than by age.

## 2.1. Method

### 2.1.1. Participants

123 children (mean age = 72.55 months, range = 37 to 101 months) were recruited from an Irish primary school and preschool over a two week period. An information letter was sent to the parents of all children (approximately 220) from Primary 1 (typically 4-5 year olds) to Primary 3 (typically 6-7 year olds) and the adjoining preschool. There were 71 girls (58%) and 52 boys (42%), 18 children wrote with their left hand and 105 wrote with their right hand. Table 1 shows the number of children at each school year level. Participants were tested alone and the language tasks typically took less than three minutes per child. All standard ethical and administrative procedures were followed.

Table 1

*The Number of Children at Each School Year Level and Their Mean Age in Months*

	<i>N</i>	Mean Age (in months)	Standard Deviation
Preschool	25	48.27	4.63
Primary 1	26	67.16	4.35
Primary 2	29	74.52	4.94
Primary 3	43	89.05	5.67

### 2.1.2. Materials and procedures

**Language experience:** A computer program was used to present individual letters, in modified comic sans font (a font with which the children are familiar as it is used in schools). Lowercase letters were chosen as the lowercase is taught first in Irish primary schools. The 18 letters presented were *a, c, e, f, g, h, j, k, l, m, n, q, r, s, t, u, y*, and *z*. The letters *b, d* and *p* were excluded as their mirror image is the correct (or very close to the correct) form of another letter. The letters *q* and *t* were modified for inclusion by adding ‘tails’ to the letters. The letters *i, o, v, w*, and *x* were excluded as they are symmetrical. The letters used were classed as either left-facing/non-directional or right-facing (Table 2). This classification was based on whether the letter had its distinctive features on the left (e.g. *a* has its loop to the left of its vertical line) or the right (e.g. *h*). As the letters *s* and *z* do not clearly face either direction, they were labelled non-directional and were included with the left-facing letters as they do not comply with the ‘right writing rule.’ Each letter was presented to the participant individually, and they were asked to name the letter. Their responses were recorded. Either the letter name or sound were accepted as correct answers.

Table 2

*Classification of Letters as Left-Facing/Non-Directional or Right-Facing*

Left-Facing/Non-Directional	Right-Facing
<i>a</i>	<i>c</i>
<i>g</i>	<i>e</i>
<i>j</i>	<i>f</i>
<i>q</i>	<i>h</i>
<i>s</i>	<i>k</i>
<i>u</i>	<i>l</i>
<i>y</i>	<i>m</i>
<i>z</i>	<i>n</i>
	<i>r</i>
	<i>t</i>

**Writing:** The children were to engage in a dictation task. They were asked to write the letters they identified correctly during the test of language experience, dictated in alphabetical order, on a plain sheet of white paper. They were also asked to write their first names. The

writing of letters was assessed and classified into three categories; a) correct (readable) horizontal writings, b) mirror writing of correct (readable) writing and c) incorrect writing (omission, uppercase, unreadable). The incorrect writings were omitted from the study (examples of which can be found in Figure 2 and Appendix A).

A By-Letter Mirror Writing Score for each of the 18 letters was calculated based on the proportion of readable letters mirror written, i.e.  $\text{Mirror Writings} \div \text{Times Letter was Written}$ . A mirror writing percentage was calculated for each child using the method devised by Fischer & Tazouti (2011). A score of 50% was given if their name was written from right to left, a score of 0% was allocated if they wrote their name from left to right. Intermediate percentage scores were given based on the proportion of letters mirror written in their name. For example if 'John' mirror wrote the *J* in his name which was otherwise correctly oriented, a percentage of 12% would be given (i.e.  $\frac{1}{4}$  of 50%). The proportion of reversed letters written during the dictation task accounted for the other 50% (see Appendix A for an example)

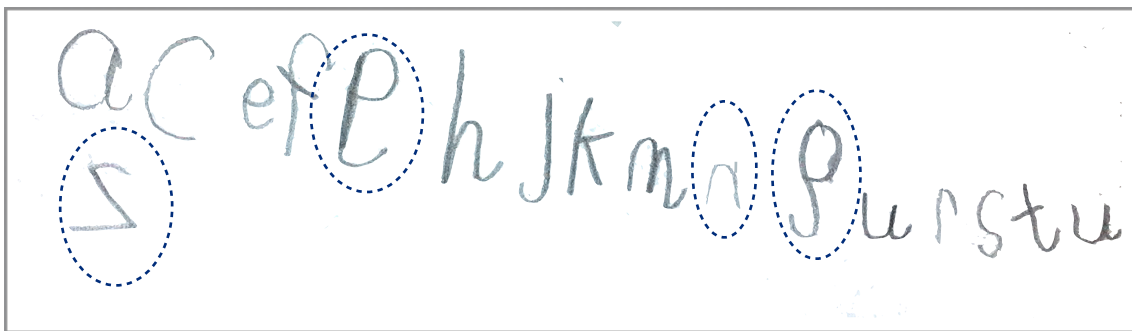


Figure 2: An example of mirror writing of individual letters. The letters g, n, q and z are mirror written by this child. The letter y was not written (an example of omission).

**Perceptual orientation decision (P.O.D) task:** A computer program was written to present the participants with letters and their mirror images. The letters correctly named during the language experience test were selected for use in this section of the assessment. The letters correctly named were presented individually at random in both their correct and mirror forms. They were asked to indicate whether the images presented to them were correct or incorrect; “Can you tell me if these letters look right or wrong to you?”

A By-Letter Perceptual Confusion Score was calculated for each of the 18 letters based on the proportion of errors made i.e.  $\text{No. of Errors} \div \text{No. of Times Letter was Presented during the P.O.D. task}$ . A perceptual confusion percentage was calculated for each child. This was based on the proportion of perceptual confusions made during this task i.e.  $\text{No. of Errors} \div \text{Total No. of Letters Presented}$ .



### 2.1.3. Statistical Methods

The alpha level was set to .05 throughout. Non-parametric analyses were chosen, as the scores from all aspects of the study were positively skewed due to ceiling effects.

## 2.2. Results

### 2.2.1. Association between letters mirror written and letters perceptually confused

To test the hypothesis that there is a correlation between letters mirror written and letters perceptually confused, a Spearman's Rank Order Correlation was used. There was a significant correlation between the By-Letter Mirror Writing Scores and the By-Letter Perceptual Confusion Scores,  $r_s(16) = .62$   $p < .01$ . Figure 3 shows this correlation.

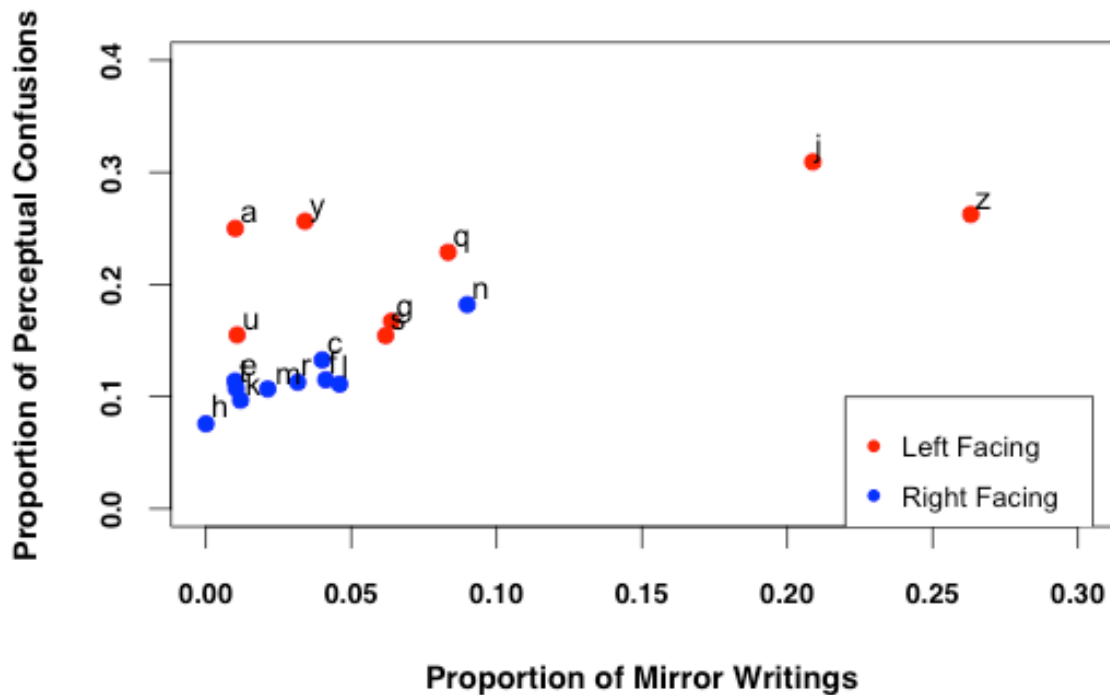


Figure 3: Correlation between By-Letter perceptual confusion and By-Letter mirror writing scores. Left-facing/ non-directional letters are shown in red, right-facing letters are shown in blue.

As can be seen in Figure 3, the three most frequently mirror written letters were  $z$  (26%),  $j$  (21%), and  $n$  (9%), two of which are left-facing. The three most frequently confused letters during the perceptual orientation task were the left-facing letters  $j$  (30%),  $z$  (26%) and  $y$  (26%).

A Mann-Whitney U test was conducted to test the hypothesis that letters which have their distinctive features on the left and those with no obvious direction are more frequently mirror written than right-facing letters (as described in Table 2). The median proportional mirror writing scores for left and right-facing letters are shown in Table 3. The results of the test were not significant,  $U = 22, p = .11$ . The left-facing/non-directional letters were not more frequently mirror written than right-facing letters.

Table 3

*Median Proportional Mirror Writing and Perceptual Confusions Scores for Left-Facing/Non-Directional ( $n = 8$ ) and Right-Facing Letters ( $n = 10$ )*

	Left-Facing Letters		Right-Facing Letters	
	Mdn	IQR	Mdn	IQR
Proportion of Mirror Writing	.06	.02 - .18	.03	.01 - .04
Proportion of Perceptual Confusions	.24	.16 - .26	.11	.10 - .12

A Mann-Whitney U was also conducted to test the hypothesis that left-facing/non-directional letters were more frequently confused during the perceptual task. The test revealed that this difference was in the expected direction and significant,  $U = 3, p < .01, r = .8$ . The median proportional perceptual confusion scores for left and right-facing letters are shown in Table 3.

### **2.2.2. Personal characteristics of mirror writers**

Table 4 details the demographic features of the children classed as writers (those who wrote their names and/or individual letters), according to whether they were normal writers or mirror writers. Mirror writers were classed as such if they showed at least one instance of mirror writing.

A similar number of boys and girls were classed as mirror writers  $\chi^2(1, N = 56) = .71, p = .79$ . There were no more left handed children in the mirror writing group than there were in the normal writing group,  $\chi^2(1, N = 16) = .00, p = 1$ . Mann Whitney U tests revealed that mirror writers were significantly younger than normal writers,  $U = 727, p < .01, r = .4$  and had received significantly fewer years schooling,  $U = 705, p < .01, r = .5$ . A significant difference between the perceptual confusion scores of normal writers and mirror writers was

found,  $U = 615$ ,  $p < .01$ ,  $r = .5$ , with mirror writers making perceptual confusions more than twice as frequently.

Table 4

*Demographic Features of Children (N = 106) who Showed at Least One Instance or Did Not Show Episodes of Mirror Writing*

	Normal Writers	Mirror Writers
No. of Children	50 (47.2%)	56 (52.8%)
Age (months)	81.14 (SD = 11.8)	71.37 (SD = 12.8)
Gender (M/F)	15/35	29/27
Handedness (R/L)	42/8	28.8
Years of Schooling	2.46	1.59
Perceptual Confusions %	10.8%	24.4%

Note: M= Male, F= Female, R= Right handed, L= Left handed.

### **2.2.3. Association between mirror writing and perceptual confusion in children**

A Spearman's Rank Order Correlation was employed to test whether there was an association between mirror writing percentage and perceptual confusion percentage. This test revealed a statistically significant correlation,  $r_s(104) = .51$ ,  $p < .01$ , with high mirror writing percentage associated with a higher proportion of perceptual confusions (Figure 4).

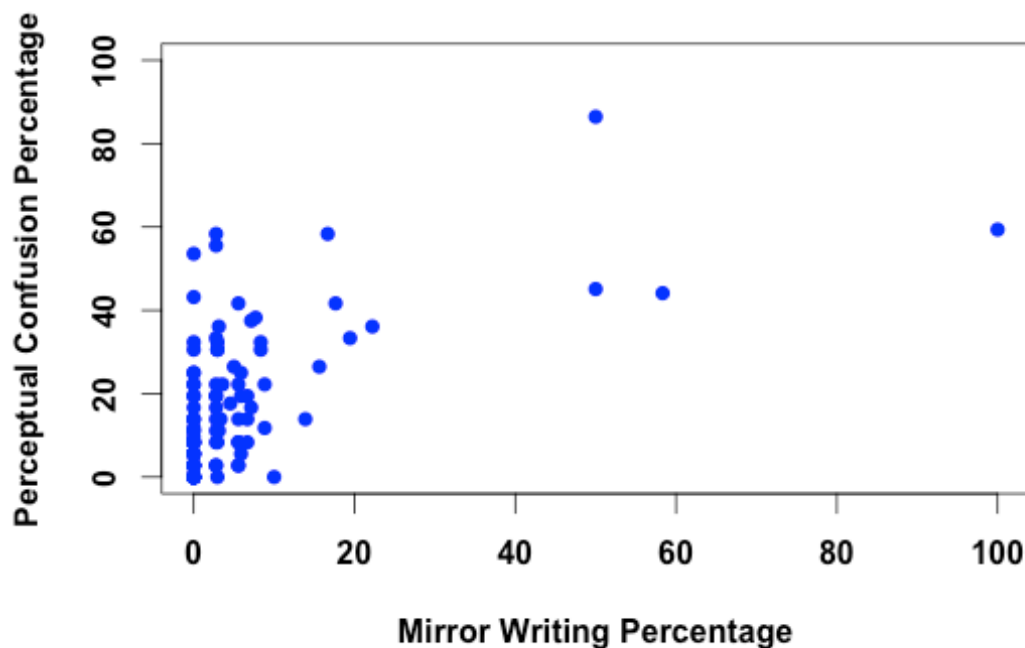


Figure 4: Correlation between mirror writing percentage and perceptual confusion percentage.

Table 5

*Correlations between Mirror Writing, Perceptual Confusion, Age (in Months), School Year and Letters Correctly Identified*

	Mirror Writing (%)	Perceptual Confusions (%)	Age (in Months)	School Year	Letters Identified
Mirror Writing (%)	–				
Perceptual Confusions (%)	.513 **	–			
Age (in Months)	-.516 **	-.591 **	–		
School Year	-.538 **	-.622 **	.941 **	–	
Letters Identified	-.409 **	-.394 **	.721 **	.695 **	–

Note: \*\*  $p < .01$  (2 tailed).

A number of other factors significantly correlated with both mirror writing percentage and perceptual confusions. These correlations are summarised in Table 5. The association between the principle factors and both age and years of schooling was examined to determine which was the critical factor in describing the tendency to mirror write. There was a very strong correlation between ‘Age in Months’ and ‘Years of Schooling.’ Thus, they both correlated with the other factors to a very similar degree. The association between the number of letters identified and mirror writing/perceptual confusions was also examined to determine whether the number of letters children knew was related to their tendency to mirror write. These correlations were weaker than those with age and years of schooling. However, there were stronger correlations between number of letters identified and both school year and age.

#### ***2.2.4. Developmental trends for mirror writing and perceptual confusions***

Table 6

*Mean Mirror Writing and Perceptual Confusion Percentages across School Years and for Normal Writers and Mirror Writers*

	Mirror Writing			Perceptual Confusions		
	<i>n</i>	Mean Percentage	SD	<i>n</i>	Mean Percentage	SD
Preschool	9	36.11%	32.81	11	45.45%	22.88
Primary 1	25	8.09%	11.93	25	26.17%	13.16
Primary 2	29	3.52%	4.50	29	15.47%	12.60
Primary 3	43	1.12%	1.95	43	8.06%	8.69

Table 6 shows the mean mirror writing and perceptual confusion percentages for each school year group. Mirror writing percentage decreased from 36% in Preschool to 1% by Primary 3. Perceptual Confusion Percentage also progressively decreased from Preschool (45%) to Primary 3 (8%). Two of the children in Preschool engaged in the P.O.D task but could not write the letters they could identify. There was a significant difference between the mirror writing percentages of Preschoolers and children in Primary 1,  $U = 59$ ,  $p = .04$ ,  $r = .4$ , between children in Primary 1 and Primary 2,  $U = 244.5$ ,  $p = .04$ ,  $r = .3$ , and in Primary 2 and Primary 3,  $U = 423.5$ ,  $p < .01$ ,  $r = .3$ . Mann-Whitney U tests also revealed significant differences between the perceptual confusion percentages of between children in Preschool and Primary 1,  $U = 55.5$ ,  $p < .01$ ,  $r = .5$ , Primary 1 and Primary 2,  $U = 180$ ,  $p < .01$ ,  $r = .4$ , and Primary 2 and Primary 3,  $U = 367.5$ ,  $p < .01$ ,  $r = .3$ .

### 2.3. Discussion

These results show strong support for a perceptual basis of mirror writing. The first hypothesis was supported; the By-Letter mirror writing scores correlated significantly with By-Letter perceptual confusions scores. In other words, the letters mirror written were those mirror read. Also, there was a correlation between the children's mirror writing and perceptual confusions percentages; children who made the most perceptual confusions were also those with the highest mirror writing percentages. This was further supported by the significant difference between the perceptual confusion percentage scores of normal writers and mirror writers. Children appear to generalise letters to their mirror image (as suggested by Dehaene, 2007) although it is very unlikely that they were ever exposed the mirror images of the lowercase letters. Furthermore, it supports a perceptual basis of mirror writing; mirror writers tend to be more confused about the orientation of letters than normal writers. These perceptual confusions appear to be directly related to mirror writing.

The By-Letter perceptual confusions scores were greater than the By-Letter mirror writing scores for every letter, except *z* which had an equal percentage of errors for writing and reading (26%). Developmental trends emerged for both mirror writing and perceptual confusions, although the perceptual confusion percentage was higher than the mirror writing percentage at every school year level. The unlearning of mirror generalisations seems to take up to three or four years of reading language experience, and lasts beyond the mirror writing

phase. These results suggest that mirror invariance may be the causal or limiting factor of mirror writing. Mirror writing may be a result of mirror generalisation. As mirror writers are unsure of the orientation of letters, mirror writing may occur when they choose the incorrect alternative from the two orientations they perceive to be correct. This would also explain why children tend to mirror write from memory more often than when they copy letters (Fischer & Tazouti, 2011). Children would have to rely on their own internal representations of the letters (and implicit knowledge) when writing from memory, occasionally choosing the incorrect orientation for their writing, most commonly affecting the left-facing letters. Alternatively, it may be that children can only end their mirror writing phase when they can identify the correct orientation of letters. In other words, they cannot correct their own mirror writing until they can ‘see’ it. This cannot happen until they have unlearned the mirror images of those letters. It is also possible, although less likely, that the mirror writing and perceptual confusion measures correlate as they are both coincidentally related to age or stage of language acquisition.

The second hypothesis was partially supported. There is a greater tendency to perceptually confuse, but not mirror write, the left-facing and non-directional letters. In particular, the letters *j* and *z* had the highest proportion of errors when written and when read. As there is a high number of left-facing and non-directional letters in the lowercase, with eight left-facing/non-directional and ten right-facing, the ‘right writing rule’ may not be as obvious in the lowercase, which may explain why there was no significant difference between the mirror writing of left-facing and right-facing letters in this sample. This ‘rule’ is more apparent in the uppercase as only three letters (*J*, *S*, and *Z*) contradict, or do not match the rule (Brennan, in press).

An alternative explanation may be that *n* and *u* may not be suitable for inclusion in a study such as this. They may be ambiguous in the sense they are the ‘upside-down’ versions of one another, and have been found to be confused perceptually albeit to a lesser degree than lateral reversal pairs, such as *b* and *d* (Davidson, 1935). With these letters removed, there is a clear distinction between the cluster of rarely mirror written and mirror read right-facing letters and the frequently confused left-facing letters. Future studies may consider excluding these letters. Alternatively, as other studies have not found *n* (Reinvang, 1972) or *N* (Fischer, 2011a) to be frequently mirror written, the high proportion of mirror writing (and perceptual confusions) for *n* may be specific to this particular sample of children. Hand writing practice

and the development of motor memories for letters (Longcamp, Zerbato-Poudou, & Velay, 2005), may explain why the left-facing letters *a* and *u* were mirror written less than 1% of the time. As the vowels are used in Consonant-Vowel-Consonant words (e.g. cat, sun) frequently used by children learning to write, it is likely children have practised writing them often enough not to make reversal errors, even though they have not yet unlearned their mirror images. As the letters *j* and *z* are among the lowest frequency letters (Lewand, 2000), they may not be well practised and therefore would not have a strong motor memory. Children would be faced with a choice of orientations (which may be influenced by the ‘right writing rule’) rather than ‘automatically’ writing the letter correctly. Replication is needed to clarify these findings.

Fischer’s (2011a) proposed explanation for the ‘right writing rule’ could be adapted to explain this study’s findings, if there were a causal relationship between mirror generalisations and mirror writing. Children may develop a ‘right *reading* rule’ rather than a ‘right writing rule’ *per se*. As most letters (both upper- and lower-case) and digits are right-facing, children may develop implicit knowledge about the orientation of letters. This ‘rule’ may not be so implicit in all children as one child commented during the P.O.D task ‘I know, all the letters going [right] are right, and all the ones going [left] are wrong!’ It seems that children may assume that all letters should be right-facing. This may mean that the mirror images of the left-facing letters are more regularly activated than the mirror-images of the right-facing letters, and hence would be retained for longer. This perceptual confusion about the correct orientation of the left-facing letters would manifest itself through mirror writing when the incorrect orientation is chosen by the child for their writing.

This study supports recent findings that mirror writing is not a left-handed phenomenon, with an equal amount of left-handed children being classed as mirror writers and normal writers. The results confirm that mirror writers tended to be both younger and have fewer years schooling than normal writers. As there was such a strong correlation between both age and years of schooling, it is not possible to determine which is the critical factor. However, it seems that mirror writing and perceptual confusions are more related to stage of writing acquisition than age, as was previously suggested (Della Sala & Cubelli, 2007; Fischer & Tazouti, 2011). The number of letters known does not appear to be directly associated with the tendency to mirror write, but rather it is likely that association between letters correctly identified and errors in writing and the P.O.D task is very closely linked to writing (and reading) acquisition.

### **3. Part 2: Testing and Extending the Directional Apraxia hypothesis to Novel Motor Tasks**

A set of simple novel motor tasks were devised for this experiment to examine whether there is a motor basis for mirror writing. The children were expected to learn that a specific toy works in only one direction. This first movement on the first toy given to the child can be taken as their initial directional preference for motor actions, as no information was given about how the toy might work. As it is assumed that abductive movements are more natural (Dreman, 1974; 1977), it would be expected that this influences spontaneous motor behaviour. It is expected that for the youngest right-handed individuals there should only be slight rightwards bias for initial directional preferences, as their motor systems are believed to be bi-directional (Della Sala & Cubelli, 2007). This directional preference should strengthen with language experience, as those who have learned specific directionality (or rather have unlearned one direction) should rely on abductive movements when directionality is not known (Della Sala & Cubelli, 2007).

This training period for the task was completed using the dominant hand. Developmental trends were predicted for directional learning. As this task requires a specific learned direction, the directional apraxia hypothesis (Della Sala & Cubelli, 2007) would predict that mirror writers would be impaired in learning the specific directional information compared to normal writers. Also, it is expected that the ability to learn the directionality of the toys would improve with age.

The directional information from the learning task was then tested during a transfer task, in which they used their non-dominant hand. As it is assumed that mirror writing reflects a widespread problem with the directionality of specific learned motor actions, those mirror write would appear to learn the directionality of the toy, would not learn the direction of the action learned *per se*, but rather they would learn the movement (abductive or adductive) used to complete the action. Thus, mirror writers would learn directions in a movement-centred manner (abductive or adductive) and transfer the action incorrectly with the left-hand, whereas normal writers would learn the direction of the toy (either left or right) and would be expected to make the necessary mental transformations to carry out the action correctly with their left hand. For example, if a child were to learn to work a toy rightward with the right hand they may try to work it leftwards with the left hand, maintaining the abductive



movement used to complete the training task. It was also expected that the proportion of correct toy-centred movements would increase with age.

Three main hypotheses can be derived to examine whether there is a motor explanation for mirror writing;

- Youngest children will show an initial preference for abductive motor actions with the right hand. This rightwards preference will be strengthened by writing experience.
- There will be a developmental trend, with motor learning scores increasing with age. Mirror writers will have lower learning scores than normal writers.
- It is expected that the likelihood of choosing (correct) toy-centred actions over (incorrect) movement-centred ones increase with age. Mirror writers will be more likely to choose movement-centred actions more often than normal writers.

The experimental design allowed for two other secondary hypothesis related to the generalisation of directional information and global directional preferences. Just as it is essentially the same to turn a door handle as it is a tap or a dial, it is expected that operating one toy in a specific way would be the same as operating another of the same type. As two different types of toy are used in this study, it is possible to apply this to whether a child generalises directional information across toys. In a second task, global directional preferences can be examined. The participants were presented with a line of directional toys and asked to operate them one by one, with their dominant hand and then with their non-dominant hand, without being given any directions regarding the starting point. Given this free choice, it was expected that as language experience increases, participants would be increasingly likely to choose the left as a starting point, proceeding to operate the toys from left-to-right with either their right or their left hand. Young children were expected to begin with the toy closest to their hand.

### 3.1. Method

#### 3.1.1. Participants

The 123 children who participated in the language tasks also participated in the novel motor tasks. A group of 20 adults (10 females and 10 males) were also recruited to partake in the motor task only (mean age = 36.9 years, range = 18 to 80 years). One participant was left-handed and 19 wrote with their right hand. In the interest of statistical power, the data from the Preschool and Primary 1 groups were collapsed into one younger group, henceforth referred to as the Juniors, and the data from Primary 2 and Primary 3 were collapsed into a second group, which will be referred to as the Seniors. The adult data remained unchanged. Table 7 shows the number of participants in each group and their mean age in years. Participants were tested alone and were randomly assigned to one of four experimental conditions (described below). The experiment typically took less than three minutes per participant. The children in the four conditions did not differ in their mean age  $\chi^2(48, N = 123) = 59.78, p = .12$  or in the proportion of boys and girls  $\chi^2(1, N = 123) = .02, p = .90$ . There was an equal number of adults in each condition ( $n = 5$ ). All standard ethical and administrative procedures were followed.

Table 7

*The number of children at each educational level and their mean age*

	<i>N</i>	Mean Age (in years)	Standard Deviation
Juniors	51	4.39	0.90
Seniors	72	6.54	0.75
Adults	20	36.9	21.16

#### 3.1.2. Materials

Four novel, visually symmetrical toys were built for this study, two rotating toys (Rotators) which operate clockwise/anticlockwise and two sliding toys (Translators) which operate rightwards/leftwards (Figure 5). Each toy was fitted with a buzzer. By means of a concealed switch, the toy's 'correct' direction could be set to either clockwise/anticlockwise or rightwards/leftwards. For example, a translator could be set to buzz when the handle is moved to the right side, whereas it would not sound when the handle is moved leftwards. In another condition, it may be set to buzz leftwards.

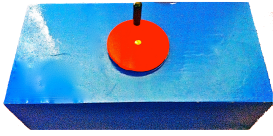
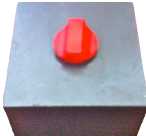


			
Rotator 1	Rotator 2	Translator 1	Translator 2

Figure 5: The novel directional toys.

### 3.1.3. Procedure and coding

The novel motor tasks consisted of two main parts. The order and directionality of the toys was counterbalanced across four conditions. This is detailed in Figure 6.


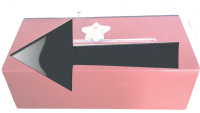



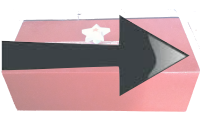
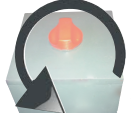

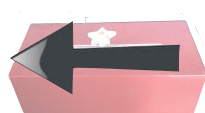
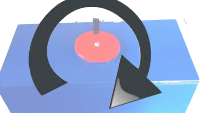


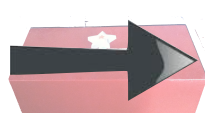
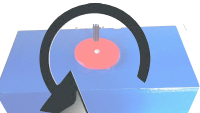
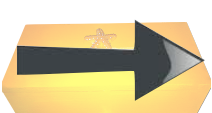

Condition 1				
Condition 2				
Condition 3				
Condition 4				

Figure 6: Order and directionality of toys in each condition.

**Train and Transfer Task:** For data collection purposes, all participants hands were video recorded during the experiment. Before the participant entered the room, the first toy, was covered by a cardboard box. When the participant was seated directly in front of the first toy, the experimenter gave a verbal instruction before the cardboard box was lifted; “When I say go, can you make this toy buzz by moving the handle, with your [dominant] hand? Go!” [as the cardboard box is lifted]

The children were gently tapped on the arm to indicate to them which hand to use. After the participant made the toy buzz, the handle was reset to centre. This was the first of four training trials. For training trials 2 - 4, the participant was simply giving the instruction “Can

you do that again?” Their directional preferences were recorded for each training trial, i.e. the direction the participant first intended to complete the action, either left/anticlockwise or right/clockwise. After these four training trials, they were then asked to make the toy buzz once with their non-dominant hand with the instruction ‘Can you do that again with your other hand?’ This was the transfer phase. Their directional preference on this trial was also recorded. After this the toy was removed, and the next was presented for the four training trials and transfer. This was repeated for the third and fourth toys.

***Toy Sequence Task:*** This task consisted of two parts. First, all four toys were presented in a row in the order they were presented in during the Train and Transfer Task. The participants were asked to make each the toys buzz once with their dominant hand. The participants were then instructed to make each toy in the row buzz once with their non-dominant hand.

#### ***3.1.4. Statistical Methods***

The alpha level was set to .05 throughout. As the scores from all aspects of the study were positively skewed due to ceiling effects, non-parametric analyses were chosen.

### **3.2. Results**

#### ***3.2.1. Initial directional preference***

Initial directional preference was recorded for each child for the first trial of the first toy presented to each child. The first toy presented was dependent on the condition the participant was assigned to. For some ( $n = 70$ ), the first toy presented to them was a Translator, for others ( $n = 73$ ) the first toy presented was a Rotator. Binomial tests were run to determine whether there was an initial directional preference ( $p = .5$ ). Left handers ( $n = 19$ ) were removed from this analysis, as combining the two would confuse interpretation of abductive/adductive movements. Figure 7 shows the proportion of participants in each group who chose a clockwise/rightwards movement for their initial directional action.

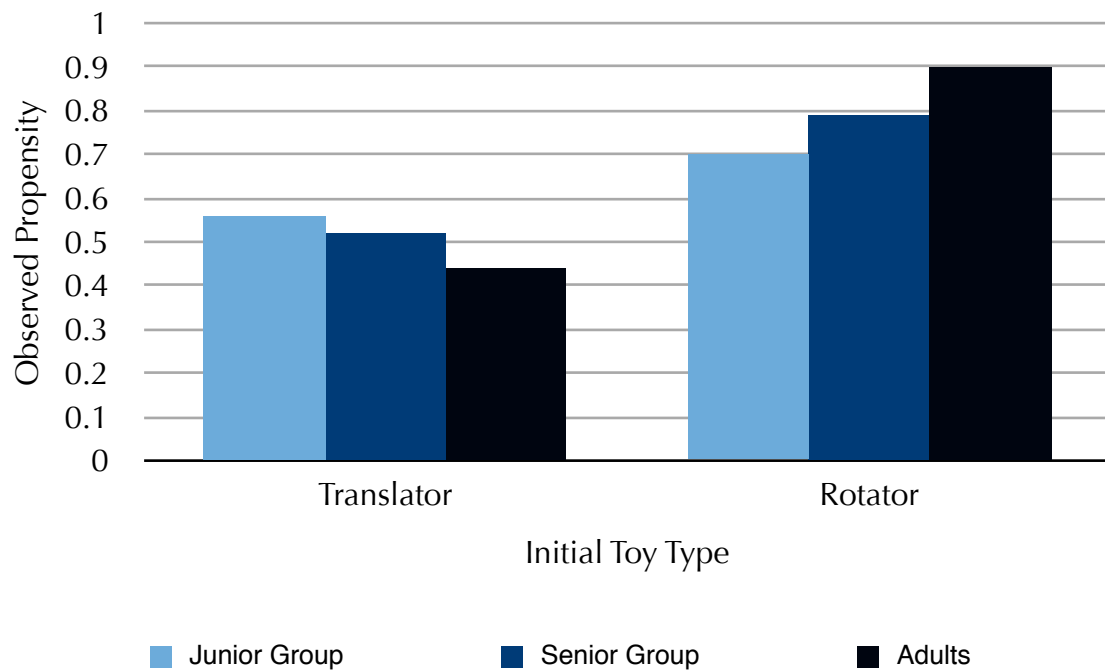


Figure 7: Observed propensity of clockwise/rightwards movements for each educational level group for rotators and translators.

**Translator:** These toys were used to test the hypothesis that abductive movements would be increasingly preferred. Thus, the right-handed participants would be expected to choose rightwards movements. Fourteen of the 25 children in the Junior Group chose a rightwards movement for their initial movement, ( $p = .69$ ). Sixteen of the 29 children in the Senior Group, ( $p = 1$ ), and 4 of the 9 Adults, ( $p = 1$ ) chose a rightwards movement for their initial directional action. No group showed a significant preference for either abductive or adductive movements.

**Rotator:** Directional preferences for Rotators were also explored. Fourteen of the 20 children in the Junior Group chose clockwise movements for their initial movement, this was not significant ( $p = .12$ ). Twenty-three of the 29 children in the Senior Group chose clockwise movements, this was significant, ( $p < .01$ ). Nine of the 10 Adults also chose clockwise movements, this was also significant ( $p = .02$ ).

### 3.2.2. The learning of specific directional motor actions

A learning score was calculated for each participant from the proportion of correct actions during trials 2, 3 and 4 for each toy. Composite learning scores for rotators and translators

were calculated for each child, as well as an overall average learning score. Two participants were excluded from these analyses due to missing data.

**Developmental Trends:** Children in the Junior Group ( $n = 49$ ) scored lower than the Senior Group ( $n = 72$ ) on average learning score,  $U = 1104.5$ ,  $p < .01$ ,  $r = .3$ . Similarly, a significant difference between children in Seniors ( $n = 72$ ) and Adults ( $n = 20$ ), was found,  $U = 474$ ,  $p < .01$ ,  $r = .3$ . Table 8 shows the sample size and median learning scores for each school year group.

**Mirror Writers:** A Mann-Whitney U test was conducted to evaluate the hypothesis that mirror writing children ( $n = 55$ ) would score lower, on average, than non mirror writing children ( $n = 50$ ) on average learning score. The results of the test were not significant,  $U = 727$ ,  $p < .46$ . The median learning scores of normal writers and mirror writers did not differ (Table 8).

Table 8  
*Median Learning and Transfer Score across School Years and for Normal Writers and Mirror Writers*

	Learning Score			Transfer Score		
	$n$	Mdn	IQR	$n$	Mdn	IQR
<b>Educational Level</b>						
Junior Group	49	0.83	0.75 - 0.92	43	0.75	0.50 - 1
Senior Group	72	1	0.83 - 1	72	0.75	0.50 - 1
Adults	20	1	1 - 1	20	1	0.75 - 1
<b>Writing Group</b>						
Normal Writers	50	0.92	0.83 - 1	46	.75	0.50 - 1
Mirror Writers	56	0.92	0.83 - 1	54	.75	0.50 - 1

**Difference between Rotators and Translators:** It was assumed, while designing the experiment, that rotators and translators would be as easy or as difficult to learn as each other. However, a Wilcoxon test revealed a significant difference between Rotators and Translators,  $Z = -2.51$ ,  $p = .01$ ,  $r = .2$ . To examine whether this difference affected learning scores across groupings, separate analysis for learning scores were conducted for Rotators and Translators across the groupings. For rotators, there was a significant difference between the Junior Group

and the Senior Group,  $U = 1407.5$ ,  $p = .02$ ,  $r = .2$ , and between Seniors and Adults,  $U = 440$ ,  $p < .01$ ,  $r = .3$ . For translators, Juniors and Seniors, did not differ significantly  $U = 1435$ ,  $p < .01$ ,  $r = .2$ , nor did Seniors and Adults,  $U = 669.5$ ,  $p = .77$ .

### **3.2.3. Transfer to non-dominant hand**

The transfer task was used to determine whether the participants learned the action in a toy centred manner (i.e. carry out the task with their left-hand in the same direction they learned during the training task, either right/clockwise or left/anticlockwise) or in a movement-centred manner (i.e. carry out the task with the left-hand incorrectly using the adductive or abductive movement learned in the training task).

To determine whether children transferred the motor direction to the non-dominant hand, it was first necessary to identify which children learned the direction information. First, children were deemed 'Learners' if they successfully made correct movements on two of the last three learning trials (i.e. trials 2, 3 or 4) for at least three of the four toys presented to them, or in other words at least two-thirds of their actions must be correct. Participants with proportional scores below .667 were not considered for this analysis. A further nine children, (11 in total) were excluded from the transfer analysis.

As the 'Learners' did not necessarily learn the direction of every toy, a transfer score was calculated on a per-toy basis. For each toy that the 'Learners' learned successfully, a transfer score was calculated based on whether their movement with their non-dominant hand was correct or incorrect. A composite score was then calculated.

**Developmental Trends:** No significant difference was found between the transfer scores of children in the Junior Group ( $n = 43$ ) and children in the Senior Group ( $n = 68$ ),  $U = 1352$ ,  $p = .48$ . There was a significant difference between children in the Senior Group ( $n = 68$ ) and Adults ( $n = 20$ ),  $U = 467.5$ ,  $p = .02$ ,  $r = .3$ . Table 7 shows the median transfer score for each school year group and the related sample size.

**Mirror Writers:** A Mann-Whitney U test was conducted to evaluate the hypothesis that mirror writing children ( $n = 54$ ) would score lower, on average, than non mirror writing children ( $n = 46$ ) on average transfer score. The results of the test were not significant,  $U =$

1184,  $p = .67$ . As can be seen in Table 6 mirror writers and normal writers have the same median transfer scores.

***Difference between Rotators and Translators:*** As with the learning scores, composite transfer scores were computed for the transfer of Rotators and Translators. A Wilcoxon test revealed no significant difference between Translators and Rotators,  $Z = -1.35$ ,  $p = .18$ .

### 3.2.4. Generalisation of Direction Between Toys

Only 'Learners' data was included in these analyses. Two measures were used to determine whether participants generalised directional information from one toy of a particular type to the next. The first measure, Type Dependent Generalisation, was whether the children generalised the directional movement across toys of the same type, i.e. to the next rotator or translator. The second, Type Independent Generalisation, was a measure of whether children generalised direction to the next toy presented to them (which was of a different type). Figure 8 shows the observed propensity for each of these measures for each of the educational level groups.

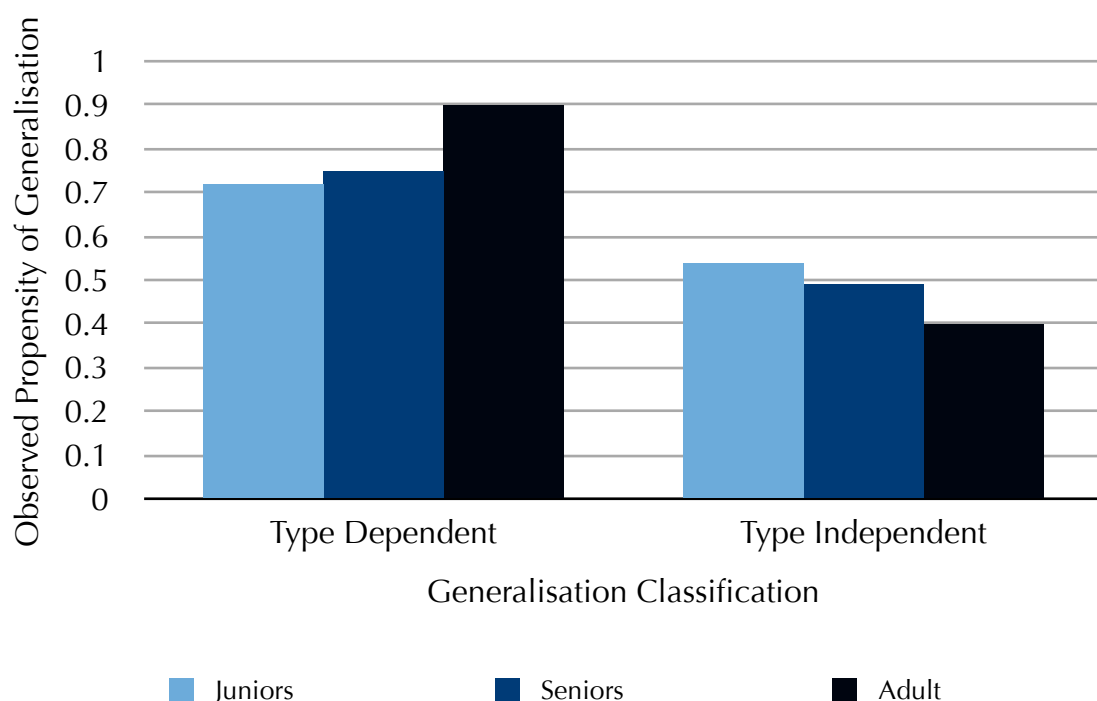


Figure 8: Observed propensity of Toy Type Independent and Toy Type Dependent Generalisations



**Type Dependent Generalisation:** Binomial tests revealed that there is a tendency to generalise directional information from the first toy of a type (rotator/translator) to the next toy of the same type. Thirty-three of the 46 Juniors generalised the directional information ( $p < .01$ ), as did 51 of the 68 Seniors ( $p < .01$ ) and 18 of the 20 adults ( $p < .01$ ). A Kruskal-Wallis Test revealed that there was no developmental trend [ $\chi^2(2, N = 143) = 2.64, p = .27$ ].

**Type Independent Generalisation:** Binomial tests revealed there was no tendency to generalise directional information from the first toy to the second. Twenty-five of the 46 Juniors did so ( $p = .66$ ) as did 33 of the 68 Seniors ( $p = .90$ ) and 8 of the 20 adults ( $p = .50$ ). A Kruskal-Wallis test revealed that this tendency did not significantly change with age [ $\chi^2(2, N = 143) = 1.02, p = .60$ ].

### **3.2.5. Global directional preference**

A Fishers Exact Test was used to determine whether there was a significant association between Toy Sequence Task with Dominant Hand and with Non-Dominant Hand and the direction chosen when carrying out the task, either right-to-left or left-to-right. Participants who did not complete the task in a linear fashion were excluded from this analysis. The association between task and direction chosen was statistically significant for Preschool children ( $p = .01$ ) and those in Primary 1, ( $p = .03$ ). However, the association between task and direction chosen was not significant, in the Primary 2, ( $p = .25$ ), or Primary 3, ( $p = .25$ ) samples. The association between task and direction chosen was not significant for adults, ( $p = .34$ ).

## **3.3. Discussion**

This study failed to support a motor hypothesis for mirror writing. A motor hypotheses (Critchley, 1928; Della Salla & Cubelli, 2007) would predict an abductive preference for the initial movement on the first translator. This study did not find any initial directional preference, either abductive or adductive for any group. For rotating movements there was a preference for clockwise actions, however, this is likely to reflect the frequent use of environmental rotators such as taps or door handles.

Secondly, although there was a developmental trend for the learning of directional actions, the hypothesis that there would be a difference in the learning scores of normal writers and mirror writers was not supported. This would suggest that mirror writing is not caused by an impairment in the learning of specific directional actions, as the directional apraxia hypothesis (Della Sala & Cubelli, 2007) would predict. While the ability to learn specific directional actions improves with age, this does not seem to be linked to the ability, or tendency, to write letters or words in their correct form.

Thirdly, among children there was no developmental trend for transfer across hands. It was predicted that the likelihood of choosing correct toy-centred actions over movement-centred ones increase with age. Older children were no better at this task than were younger children, although adults were more accurate with the transfer of directional knowledge to the non-dominant hand. On a whole, children and adults made few incorrect transfers, some of which may have reflected lapses in concentration rather than actually being movement-centred actions. Mirror writers were expected to choose (correct) toy-centred actions more often than normal writers. If mirror writing were related to an inability to correctly transform actions for use with the non-dominant hand, mirror writers would have performed poorly in this task. This hypothesis was not supported.

Overall, this study does not support a motor hypotheses of mirror writing. No abductive preference was found, and mirror writers did not perform differently than normal writers. However, the secondary hypotheses were supported. Participants generalised actions across toys of the same type, i.e. from the first rotator to the next rotator and from the first translator to the second translator. This suggests that both children and adults recognise the type of toy and choose the motor programme to operate that toy accordingly.

The hypothesis that the likelihood of choosing left-to-right directions with either hand increases with language experience was supported. A clear developmental trend was evident, revealing that reading and writing habits influence the choice of motor actions. While it was easier for right handed participants to choose a right-to-left starting point with their left hand, this became increasingly less likely as language experience increased. This supports Vaid's (1995) findings that reading and writing direction 'invades' other non-linguistic domains. This tendency to begin on the left may help reduce mirror writings (Cornell, 1985).

## **4. General Discussion**

It now seems unlikely that there is a unitary account for mirror writing. The directional apraxia hypothesis (Della Sala & Cubelli, 2007) remains a plausible explanation for the mirror writing found in brain damaged patients, who may temporarily lose directional information. A motor explanation also seems likely for the involuntary mirror writing in normal adults, who may fail to appropriately transform their motor actions. However, motor explanations do not seem to explain childhood mirror writing. As mirror writers are not impaired in motor learning tasks, mirror writing is not best explained as “the most overt symptom of a widespread high-order deficit encompassing all tasks requiring a learned, specific, motor direction” (Della Sala & Cubelli, 2007, p.20). Rather, a perceptual explanation may be more suited. Earlier attempts to associate orientation judgement errors (e.g. Della Sala & Cubelli, 2007) with mirror writing failed as they did not examine orientation judgements about letters. The perceptual confusion found in young children, in particular mirror writers, is not one of left or right or picking an ‘odd one out’, but rather it is specific to the mirror invariance of letters described by Dehaene (2007).

This study suggests that mirror writing is associated with the spontaneous mirror generalisations of letters. The letters mirror written tend to be those mirror read. In particular, the left-facing letters tend to be most frequently confused conforming with the ‘right writing rule.’ As the perceptual confusion scores were higher than mirror writing scores for every letter, at every school year level, it seems that mirror writing does have a perceptual basis and is strongly related to the mirror generalisation of letters (and digits). Mirror generalisations may be the limiting factor for mirror writing. Children may not be able to move beyond the mirror writing phase as the mirror writings cannot be corrected by a child until they know the correct orientation of the letters. These mirror generalisation might also be the cause of mirror writing.

Until mirror discrimination occurs, children are unsure of which direction letters should face. To very young children all letters appear correct, regardless of left-right orientation. Very young writers, who are unaware of writing conventions such as writing from left to right, may reverse whole words or sentences, depending on situational factors (Cornell, 1985), and in particular when writing from memory (Fischer & Tazouti, 2011). They may begin writing on the righthand side of a page and mirror write whole words or sentences without noticing their

writing is mirrored. Slightly older children, who are aware of writing conventions, may write the words in the correct orientation, but may reverse individual letters within those words. They perceive (at least some) letters in either orientation to be correct (Dehaene, 2007) but may know, from having their writing corrected by adults, that only one of these orientations is preferred. Children tend to mirror the left-facing letters in particular (Brennan, in press; Fischer, 2011a; Fischer, 2011b). This decision may be influenced by implicit knowledge. As most characters are right-oriented and Western languages are read left-to-right, children may develop implicit knowledge about the orientation of letters and digits. They may then use this when deciding whether to write a letter (or digit) leftwards or rightwards. When a child is unsure of the orientation of a letter, they are likely to choose the right-facing mirror generalisation for their writing. Visuospatial priming may also influence this decision (Fischer, 2011a). If the preceding letter is right-oriented, children may use this information in choosing an orientation for their writing, and, for example, reverse a *j*.

However, it is unlikely that perceptual factors alone explain the development writing in children. Reading experience (Pederson, 2003) or even age-related maturation process alone are unlikely to explain the transition from the mirror writing phase to normal writing. Although this study does not support a motor hypothesis for mirror writing, I propose that sensorimotor factors play a role. Writing by hand may help children choose the correct orientation for their writing and may aid the unlearning of the unwanted orientation of letters, leading to the end of spontaneous childhood mirror writing. There is evidence to suggest that the orientation of letters is better remembered when hand written rather than typed (Longcamp, Zerbato-Poudou & Velay, 2005; Longcamp et al., 2008). This may explain why children who no longer mirror write maintain some degree of mirror invariance. The specific gestures involved in writing may help disambiguate the letters from their mirror image, aiding their visual recognition (Pegado et al., 2011). It appears that the perceptual and sensorimotor components of writing are two separate, yet overlapping, cerebral networks (Mangan & Velay, 2010). When children consistently write letters correctly they may develop a stable motor memory for those letters which would aid the unlearning of their mirror-images. Essentially, the more practised child's hand would know the orientation before their perceptual system does, whereas a younger child would not have developed a stable motor program because they have not practised enough, which means they would have to guess (or rely on implicit knowledge) the orientation of letters. Evidence suggest that these guesses tend to orient the letters rightwards (Brennan, in press; Fischer, 2011a). Children who regularly mirror

write may be confusing themselves further, as they are not allowing themselves to develop a motor memory for those letters, and impeding the unlearning of mirror-images. Over time the visual system would unlearn the mirror generalisations, transitioning from the end of a perceptual explanation of childhood mirror writing to the beginning of the motor explanation observed in adults.

Although there is a strong correlation between age and years of schooling, the role of mirror generalisation (and writing practice) on mirror writing is apparent (Danziger & Pederson, 1998; Pederson, 2003) and it is likely that reading (and writing) experience is the critical variable as has been previously suggested (Dela Sala & Cubelli, 2007; Fischer & Tazouti, 2011; Johansson, 2005). Mirror writing should continue to be examined in terms of writing experience rather than chronological age.

#### **4.1.Limitations and Future Directions**

This study was not without limitations. As this study was designed to be exploratory and a large sample of children were to be sampled, many aspects of the study were not examined in great depth. Considering the children were only given the opportunity to write each letter once, and the majority of children were presented with each letter and its mirror image once, there may be more mirror writers and mirror readers than this sample indicates. The mean age of the children in this study is higher than would be ideal in a mirror writing study. Fischer (2011b) identifies preschool children as more suitable participants than primary school children. As the children were slightly older, it may be that there was a lower frequency of mirror writings and perceptual confusions than would otherwise be expected in a mirror writing study. Future studies could replicate the language section of the study with both upper- and lower-case letters in a slightly younger sample. Digits should also be included to gain a more comprehensive view of the ‘right writing rule’ and its perceptual basis, as other studies have documented the mirror writing of these characters (Fischer, 2011a; Johansson, 2005.) The opportunities to mirror write and make perceptual confusions should be increased by at least doubling the writing demands and exposure to the letters in the perceptual task. Future studies might also consider removing ambiguous letters such as *n* and *u*, or may test whether the same pattern of mirror writings and perceptual errors occur for these letters in another sample.

Although it was assumed that rotation and translation were comparable actions, this assumption was proven incorrect. Rotators were found to be more difficult to learn and induced stronger initial directional tendencies. This strong tendency may be due to the frequency of rotators in the environment, such as door handles, taps and bottle tops. Sliders are far less common, with few salient environmental examples e.g. sliding bolts. As these actions are not comparable to each other, it may be that they are not comparable to writing. An association between mirror writing and the learning of motor actions more similar to writing cannot be ruled out. Rather than directional apraxia in children being related to all motor learning (Della Sala & Cubelli, 2007), it may relate more specifically to motor actions similar to writing. Future studies may explore this using tasks which require fine motor skills or object manipulation similar to the use of a pencil.

The perceptual hypotheses of mirror writing should be further explored. These findings only begin to uncover a link between mirror writing and mirror reading, and the probable progression from a perceptual basis of mirror writing to a motor based explanation in adults. A more thorough measure of literacy would more accurately describe the different stages of language acquisition than years of schooling. This would provide a more suitable measure for tracking the development of mirror writing. Longitudinal studies would be particularly informative. The factors which lead to the end of mirror writing, and mirror generalisations should be identified. In particular, the influence of hand writing should be examined further (Longcamp et al., 2008). Such factors may not be limited to years of schooling or age, but may also include influences from the home environment parents and siblings and their exposure to reading and writing. This would further inform educational practice. Such longitudinal studies would also better identify the period during which mirror writing is most likely to occur while a child is learning to write.

The sample size was adequate with over 100 children, and the findings of this study were close to those of others in that the left-facing letters were more frequently perceptually confused (Brennan, in press) and were generally more frequently mirror written (Fischer, 2011a; 2011b, Reinvang, 1972). However, it would be worthwhile to extend these findings not only with larger samples, in other more diverse educational settings but also in languages which run right-to-left, such as Hebrew. It would be interesting to determine whether a rule similar to the 'right writing rule' would be found in such languages.

## 4.2. Educational Implications

Considering that when situational constraints are conducive to mirror writing, as much as 95% of preschool children mirror write (Fischer & Tazouti, 2011), it should be conveyed to parents and educators that mirror writing is a normal stage when learning to write, does not imply any dysfunction, and is not a left-handed phenomenon (Schiller, 1932). Mirror writing should be explained as a transient phase during in which the children have spontaneously learned how to write the letter(s) in the wrong direction and must go through a period of unlearning before they can write correctly. However, as mirror writing may slow the development of motor memories, and consequently hinder the skill of mirror discrimination (Longcamp et al., 2008), thus affecting efficient reading, mirror writing should be resolved quickly.

Fischer (2011b) proposed a number of recommendations to minimise mirror errors when learning to write, which will be discussed and extended. As Fischer and Tazouti (2011) found that writing from memory leads to more mirror writing than copying letters or words, clear displays of how letters and digits are written should be readily available to children in their school, or home, environments. Examples of such may be wall displays or individual number and letter lines on their desks. Children should be encouraged to check these frequently as even a brief look at correct writing is enough to reduce mirror writings (Fischer & Tazouti, 2011).

←		→
a	i	b
d	o	c
g	v	e
j	w	f
q	x	h
u		s
y		k
z		l
		m
		n
		r
		t

*Figure 9: An example of the classification of lowercase letters as left-facing, right-facing or non-directional for use in early education settings.*

The orientation of each letter could be explicitly taught as conforming to, or departing from the ‘right writing rule.’ Fischer (2011b) recommended a categorisation of uppercase letters and numbers as either left-facing, right-facing or non-directional. This can be extended to lowercase letters (Figure 9). The ‘non-directional’ letters, *s* and *z*, do not clearly face either direction, or have a ‘spine’ from which they have their distinctive features as do most others letters (e.g. *b*, *d*, *f*). However, the ‘head’s of these letters should take precedence over their ‘tails’ when judging their directionality. Therefore, the letter *s* should be taught as right-facing (as if it were an upright snake facing rightwards), and *z* should be seen as left-facing.

Children should be encouraged to consult this chart, or other environmental print, when writing and engage in the self-monitoring of their own writing. Anecdotally, children are capable of correcting their own errors when told that the letter ‘goes the other way’, although they do not ‘see’ the mistake themselves. If the children were encouraged to regularly ask themselves whether the letters or words they have written faces the same way as the environmental example, rather than asking themselves if it looks the same, they may become more aware of their own mirror writing.

Situational factors conducive to mirror writing should be minimised. A dot should be placed on the top-left of pages for young writers to indicate starting position of writing (Fischer & Tazouti, 2011). The reading and writing direction should be highlighted frequently and children should be praised and rewarded for following such conventions.

As, hand writing helps disambiguate the letters (Longcamp, Zerbato-Poudou, & Velay, 2005; Longcamp et al., 2008), children should engage in regular hand writing practice of single letters and digits, even beyond the emerging literacy stage. The regular use of computers for writing should be limited while a child is learning to read and write, if the unlearning of mirror-generalisation is to occur, in particular for ‘tricky’ letters like *p* and *q*. As the hand is at the core of human learning (Wilson, 1998), a multi-sensory approach to learning to write is also advocated (Montessori, 1952), which may involve the tactile sensations of play-dough or sandpaper letters. Rhymes and actions may serve as memory aids as well as any mnemonic which may help children learn the orientation of ‘tricky’ letters e.g. for distinguishing between the letters *b* and *d*, a child might think of the ‘posts’ of the word ‘*bed*.’



### **4.3. Conclusion**

It currently seems that mirror writing does not have a unitary explanation. Childhood mirror writing does not appear to be the same as the mirror writing observed in brain damaged patients and normal healthy adults. Mirror writing in young children appears to have a predominantly perceptual explanation. Childhood mirror writing is best described as a potential, normal and transient phase while every child is learning to write, which may be caused by the spontaneous mirror generalisation of letters and digits (Dehaene, 2007). The letters which are most frequently mirror written, and mirror read, are generally those which do not comply with Fischer's (2011a) 'right writing rule.' As situational factors and visuospatial priming are conducive to mirror writing, it is recommended that these situational factors are minimised while a child is learning to write and the orientation of each letter is explicitly taught and frequently revised.

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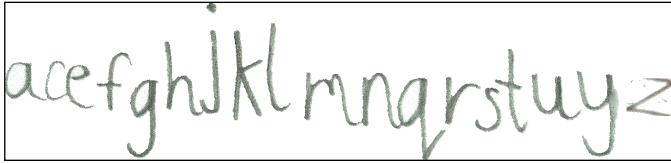
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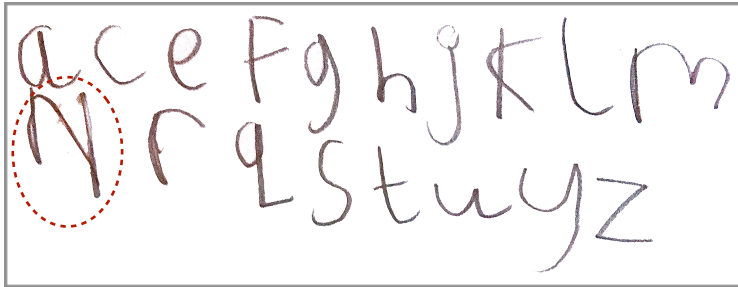
## Appendix A: Samples of Children's Writing

### *Correct (Readable) Writings*

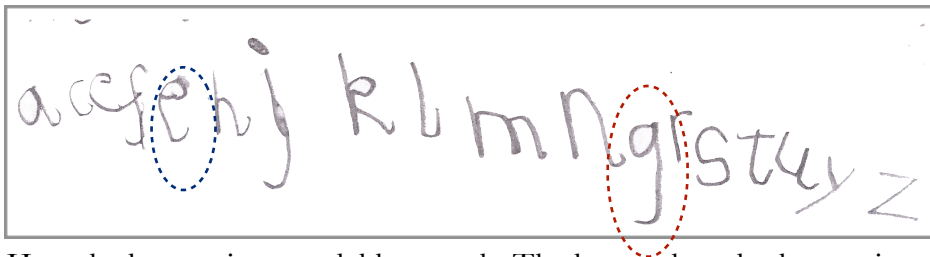


'a c e f g h j k l m n q r s t u y z'

### *Incorrect (Unreadable/Uppercase) Writing*

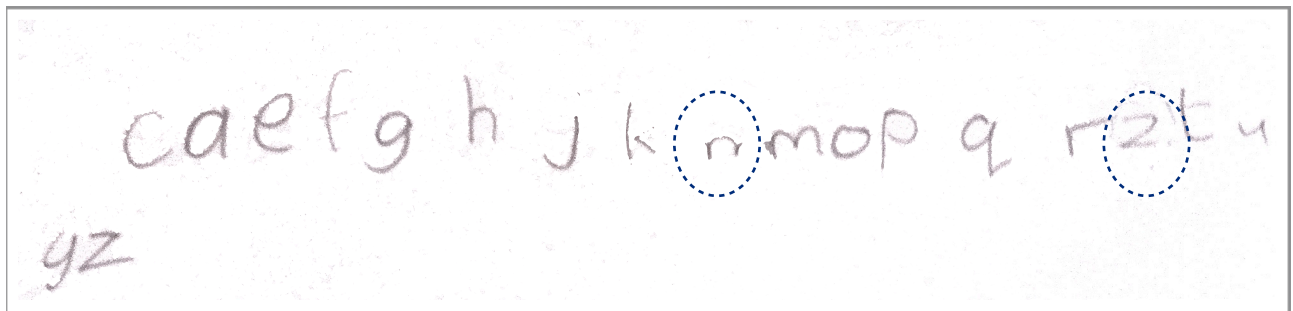


This sample contains the uppercase letter N, which was therefore omitted.



Here the letter q is unreadable as such. The letter g has also been mirror written.

### *Mirror Writing of Individual Letters*



The letters n and s are mirror written here.

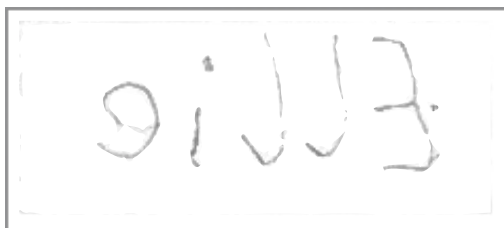
### ***Calculation of Mirror Writing Percentage***

The sample on the left contains 6 mirrored letters (c, f, k, l, s and t). Also, the letter r has not been written, and q is incorrectly written. Thus 16 letters were written. The mirror writing percentage for this sample is

$(6/16) \times 100 = 37.5\%$ .

This child did not mirror write their name. As the dictation task accounted for 50% of the mirror writing percentage, a mirror writing percentage of 18.75% was given to this child.

### ***Complete Mirror Writing of Name***



'Ellie'

### ***Partial Mirror Writing of Name***

'Jim'

